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Ecological significance of sediment biotic and geochemical effects related to the Iona WWTP outfall discharge to the Strait of Georgia off Sturgeon Bank

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The Iona WWTP outfall monitoring program has been in place since 1986. The monitoring program for Iona WWTP receiving environment effects was recently revised based on a 10-year review of the historical program (2WE Consulting 1999). Since 2000, the revised monitoring program has been designed to assess the effects of outfall particulates deposition on the benthic habitat and community. The best evidence of the distribution of Iona discharge effects on sediments prior to 2000 was the study of sediment silver by Gordon (1997). According to this study, sediment effects might be expected along the 90 m depth contour in a gradient to the north, and less so to the south of the outfall. Results of the Hodgins and Hodgins (2000) report on modeled sediment deposition of total suspended solids suggest that initial deposition is maximal upslope of the 90 m contour. Therefore, significant down-slope sediment transport is occurring over time. A compromise to identify the maximum exposure zone resulted in choosing the 80 m depth contour for sampling (see Fig. 9 below). This also eliminated the problem of depth confounding in the historical monitoring program. The cross-transect survey undertaken in 2003 (see McPherson et al. 2004) confirmed that the 80m contour is the zone of maximum deposition. The revised program has been completed annually for 2000 to 2004 (Bailey et al. 2003, McPherson et al. 2001, 2003, 2004, 2005), with a total of 16 stations with 3 replicates per station for precision and statistical assessments of patterns.

Annual Monitoring Parameters completed from 2000 to 2004 include macrofaunal abundance and biomass, conventionals (particle size, TOC, TON, TVS), Fecal coliforms (sediment and near-bottom), Total metals, SEM/AVS, Organic contaminants (chlorobenzenes, organochlorinated pesticides, PAHs, PCBs, 4-nonylphenol and its ethoxylates, phthalate esters, and selected estradiols and sterols). Other studies include the demersal adult fish surveys (English sole and Dungeness crab) in 1993 and 2001.

Based on the model by Hodgins and Hodgins (2000), the maximum modelled deposition of outfall particulates in the Iona receiving environment is ~1gC/m2/dy, which is considered to be within the assimilative capacity of soft sediments for organic deposition suggested by Hargrave et al. (1997) to maintain sediment quality (based on fish farm depositions). Sediment total organic carbon (TOC) levels are consistently low in the area (fig. 1), and tend to be related to sediment particle size. The low organic content even within close proximity of the outfall is probably due to much higher inorganic input of particulate material from the south arm of the Fraser River during freshet. Thus, there is no evidence of organic buildup in the sediments over time.

However, sediment acid volatile sulphides (AVS) values (fig. 2) show a temporally-consistent zone of sediment geochemical change related to the discharge resulting from the production of hydrogen sulphide by bacteria living at the oxic/anoxic boundary in sediments, and the input of organic material.

In addition to AVS, there are a number of organic contaminants and metabolic byproducts that are consistently good indicators of the Iona outfall particulate deposition. Metallic and organic contaminants are predominantly well below provincial sediment quality guidelines. PAHs are related more to background signal from Burrard Inlet and Fraser River, and metals and most organic contaminants appear to be unrelated to biotic effects, except for the few good indicators such as coprostanol (fig. 3) and 4-NP. Coprostanol is not considered to be toxic, whereas CCME (2002) has developed interim marine sediment quality guidelines for 4-NP of 1 mg/g for 1% TOC toxic equivalency units (about 5 times greater than maximum values measured in the Iona receiving environment).

Based on the distribution of metallic and organic contaminants, and modeled particulates deposition, the majority of the outfall particulates settle to the north of the outfall, with a net north and down-slope transport over time.

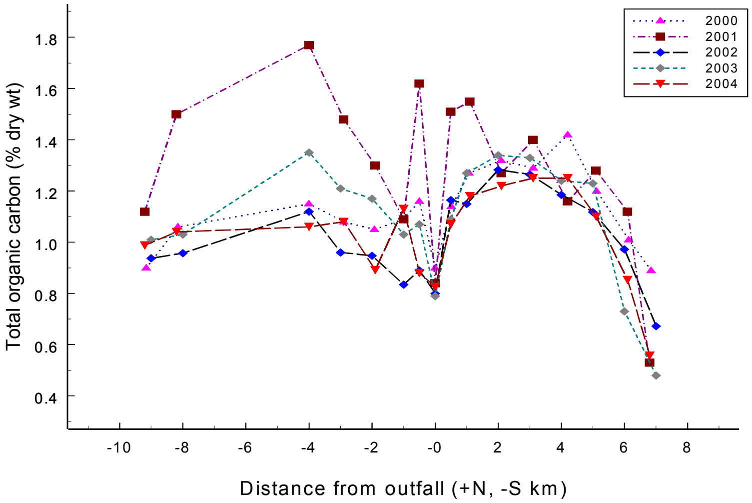

Figure 1. Temporal patterns in total organic carbon in sediments for the Iona monitoring gradient.

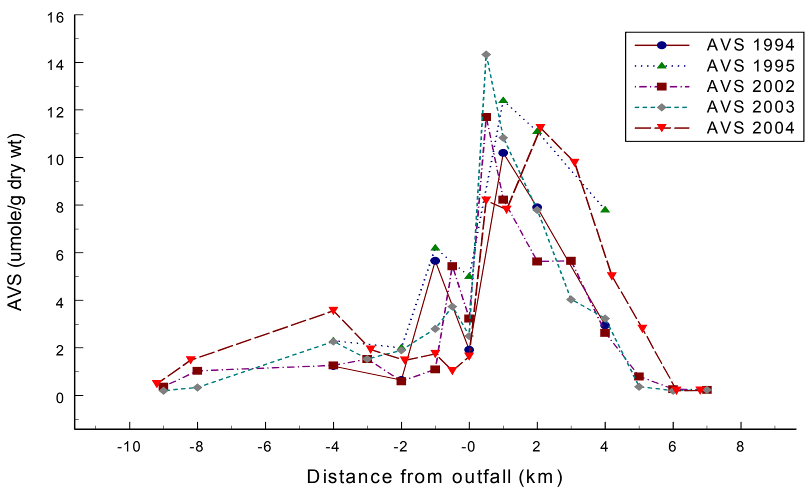

Figure 2. Temporal patterns in sediment acid volatile sulphides (AVS) for the Iona receiving environment.

There has been one notable change in the sampling program at Iona over the 5 year period from 2000 to 2005. Field and laboratory quality control and procedures for biological samples were modified between 2000 and 2001. The resulting change in taxonomic richness and abundance of samples is startling (Fig. 4). Methods have been consistent from 2001 to 2004. This clearly highlighted the need to continuously monitor methodology and reference ranges in the sampling program.

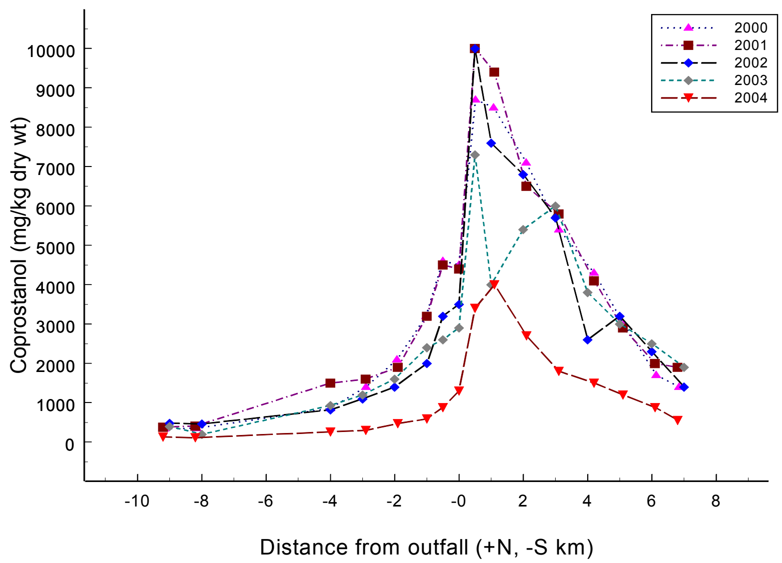

Figure 3. Temporal patterns in metabolic by-products from the Iona outfall from 2000 to 2004.

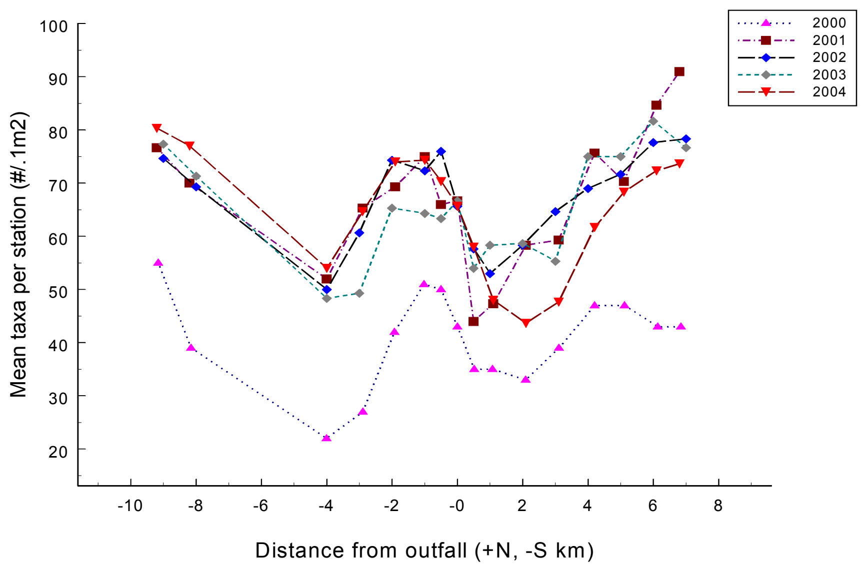

Figure 4. Temporal patterns in mean taxa number from the Iona monitoring gradient, 2000 to 2004.

Some general biotic patterns over time show a relative consistency in pattern related to the outfall. They also show some interesting confounding influences unrelated to the outfall. There is a variable and moderate decline in species richness (fig. 4), abundance (fig. 5) but not biomass (fig. 6) at some stations within about 3 km N of the outfall. However, there is a second such decline evident at 3-4 km south of the outfall, outside the deposition zone from the outfall (based on modeling and distribution of outfall chemical indicators). No sediment geochemical or contaminant changes are evident in this zone, and the biotic patterns (loss of near-surface fauna and proliferation of deeper burrowers with no increase in dominance of enrichment or tolerant opportunists, Burd 2003) suggest that the disturbance may be due to an ongoing surficial disruption of some kind. The effect is temporally variable, but always most extreme at 4 km south, variably evident at 3 km south, and slightly evident in the odd grab sample from the surrounding stations 2 and 8 kms S.

In addition, patchy incursions of high levels of contaminants unrelated to Iona, considerable biotic variability and unusually high sand content relative to the other stations, has made station 1 at the north end of the sampling gradient (Fig. 9) inappropriate as a reference station.

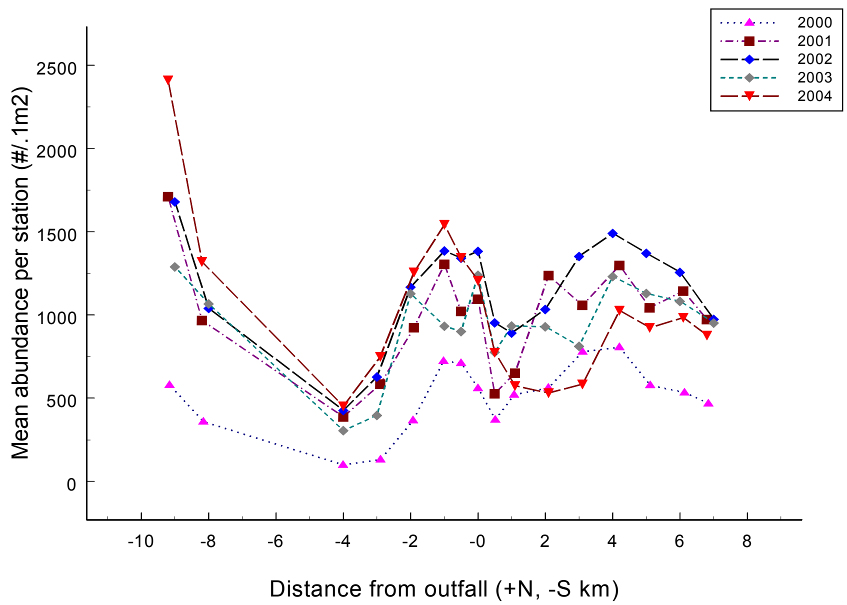

Figure 5. Temporal patterns in mean abundance per station for the Iona receiving environment, 2000 to 2004.

Certain taxa are also consistently indicative of the outfall effects. The first example given is an ophiuroid, *Amphiodia urtica* (fig. 7), which is also a dominant as far south as southern California, and tends to be a mild to moderate organic enrichment opportunist, but with limited tolerance to sediment geochemical degradation (for review see Burd 2003). This species is consistently displaced in the heaviest deposition stations to the N of the outfall, and enriched in zones surrounding this area. Historical data suggests that this species was much less abundant in the area prior to the commissioning of the outfall.

A more classic enrichment opportunist known to be tolerant of low oxygen and high sulphide levels, is the polychaete *Capitella capitata complex*. This species (fig. 8) shows a consistent but modest enrichment in the heaviest deposition zone over time.

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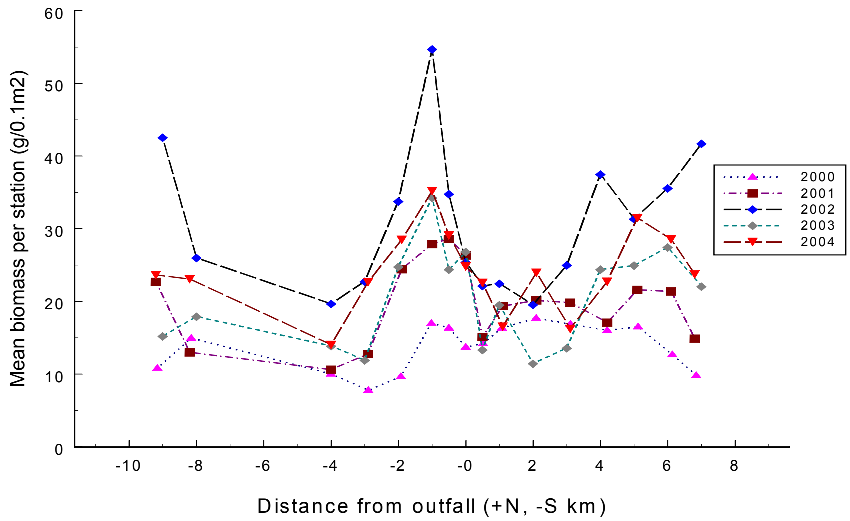

Figure 6. Temporal patterns in mean biomass per station for the Iona receiving environment, 2000 to 2004.

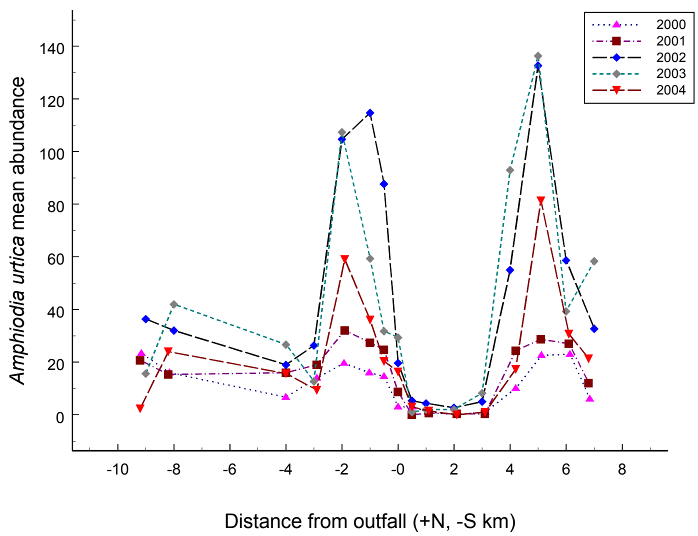

Figure 7. Temporal patterns in mean abundance of the ophiuroid *Amphiodia urtica* per station for the Iona receiving environment, 2000 to 2004.

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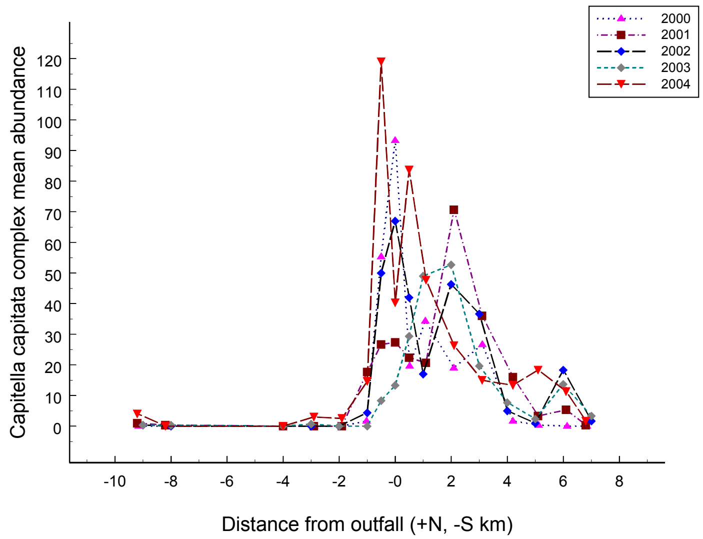

Figure 8. Temporal patterns in mean abundance of the organic enrichment opportunist *Capitella capitata complex* per station for the Iona receiving environment, 2000 to 2004.

Consistent patterns in biotic effects are evident along the exposure gradient, both in terms of sediment contaminants and biotic composition (fig. 9).

Moderately impacted (MI): moderate declines in abundance, species richness, biomass and the most abundant bivalve, *Axinopsida serricata*; virtual elimination of echinoderms, crustaceans, modest enrichment of opportunistic polychaetes (decreased Swartz Dominance Index - SDI); highest AVS, coprostanol and nonylphenol levels. Conditions suggest reduced oxygen in sediments. This effect zone fluctuates from ½ to 1 km north of the outfall. Faunal composition is significantly distinct in this area.

Less impacted (LI): moderate declines in species richness and SDI, with abundance and biomass variable or enriched (bivalves and polychaetes); virtual elimination of echinoderms, crustaceans; elevated AVS and sterol indicators. Conditions suggest moderate or mild hypoxia in near-surface sediments from 1-3 km N and 0- 0.5 km S of the outfall. Faunal composition is significantly distinct from the enriched and background zones.

Enriched (BE): no declines in species richness, abundance, juvenile recruitment or biomass or sediment hypoxia; enrichment of some taxa such as ophiuroids; depression of a few species; background AVS and 4-NP levels. This zone (mid-field) is between 4-5 km N and 0.5-1 km S of the outfall. This area does not show statistically significant differences in faunal composition from reference or far-field stations.

Background (R): The far-field stations 2,12,15,16 are considered to represent background or "reference" conditions. There are significant differences in faunal composition from the northern-most to the southernmost of these stations, which is probably related to the S to N gradient of input to sediments from the south arm of the Fraser River. However, the faunal complement of the aforementioned stations is considered to encompass the natural range in biotic composition for this region and habitat. Faunal composition is significantly distinct from the impoverished zones (MI,LI), but not enriched zones (BE).

Confounded(OE1,OE2): Station 1 (OE1) is 7 km N of the outfall en route to the Point Grey Dumpsite. It shows erratic and patchy disturbance, with chemistry suggestive of periodic dumping of dredged material sandier than the other Iona stations. No organic enrichment is suggested (high SDI), but faunal composition tends to be significantly distinct from other stations. Stations 13,14 (OE2) show faunal impoverishments in species richness, abundance and sometimes biomass, unrelated to organic enrichment (normal SDI and no enrichment opportunists). Near-surface species and those sensitive to surface disruption are reduced, suggesting physical disturbance variable in extent and magnitude, sometimes evident in 1 replicate sample for the surrounding stations 12 and 15.

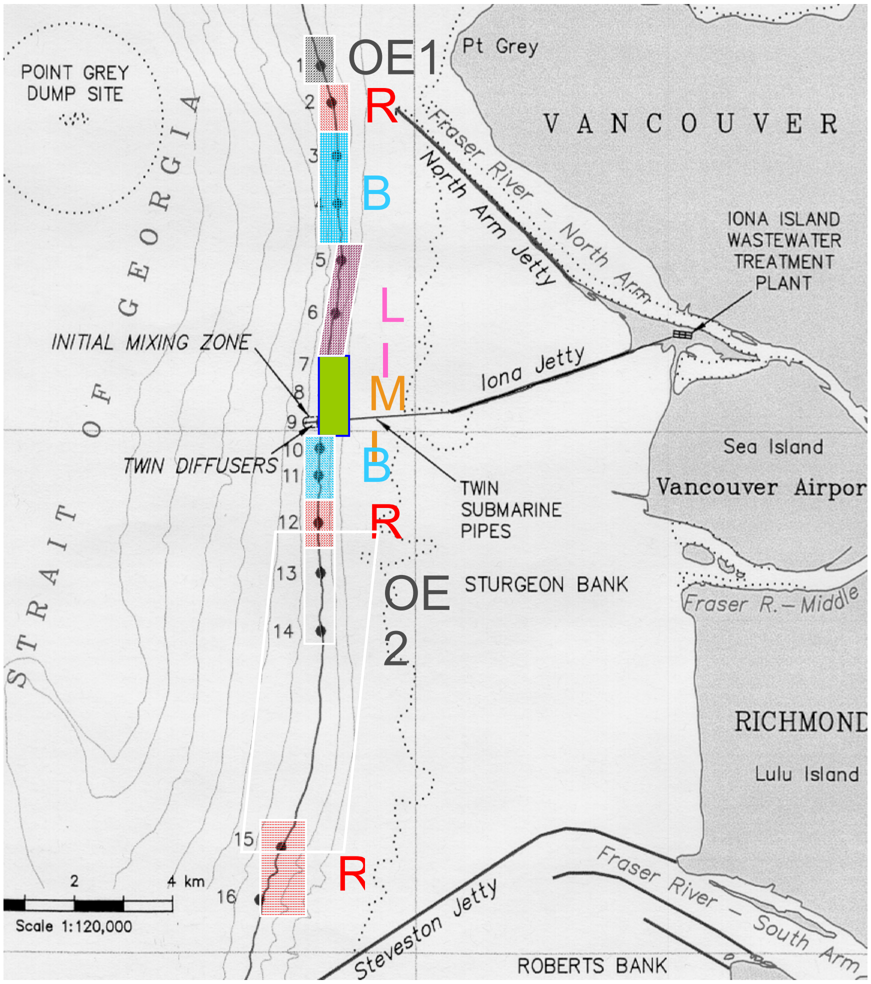

Figure 9. Extrapolated effect zones for the Iona monitoring gradient, based on data from 2000 to 2003. MI=moderately impacted; LI=low impact; B=biotically enriched; R=reference or background conditions; OE=outside effects (confounded).

Stations 2 (6 km N), 12 (2 km S), 15 and 16 (8 and 9 km S) therefore appear to provide the best background information on biotic patterns unrelated to the outfall deposition. These stations are outside any evident particulate deposition based on modeling and sediment chemical and geochemical conditions. In addition, they show biological patterns with no evidence of organic enrichment influence or contaminant influence. These stations are therefore considered "far-field" or background for comparison of effects related to the Iona outfall.

Evaluation of Effects relative to Background Ranges in each year

For the identified effect zones from Figure 11, (MI=moderate impoverishment; LI=low impoverishment; OE2 = southern other effects zone), the following general conclusions can be made on outfall effects to benthic biota based on comparison with background ranges;

- The spatial extent of biotic effects is within 3 km N and 0.5 km S of the outfall, with the most pronounced effects within 1 km N. The patterns of change are typical for organic enrichment
- There has been no notable loss in biomass near the outfall over time
- Abundance losses have been minor and variable near outfall, and up to 50% below reference all years in OE2 3-4 km south of the outfall
- There is a modest but consistent decline in species number, especially within 1 km of outfall, with similar species declines noted at OE2

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- There has been a virtual elimination of ophiuroids and crustaceans in the moderately and low impacted stations (MI, LI – within 3 km N of the outfall) and at 3-4 km south (OE2) in all years
- Faunal composition is significantly distinct in the near-field (MI, LI) and OE zones in all years
- The biotically enriched zone tends to have a composition between that of the near-field and the background

The immediate ecological significance of effects of the Iona discharge on benthic infauna can be simplistically summarized as follows (and see Burd 2003):

- Natural conditions prevent organic buildup and progressive degradation of sediments
- Observed biotic effects are moderate to mild and can be reasonably well delineated spatially
- biotic and sediment effects appear to be spatially stable based on data from 1991, 1995 and 2000-2004
- Contaminant effects are possible, but unlikely, within 1 km N of the outfall. Rather, effects are typical of sediment geochemical changes related to organic enrichment.
- Declines in ophiuroids within the MI and LI zones are of questionable ecological significance, since they are enhanced in surrounding areas of organic enrichment.
- Low numbers of crustaceans are not unusual in a variety of "clean" and impacted marine habitats. Crustaceans make up< 1% of faunal abundance and <0.1% of biomass in reference stations, and are thus a minor component of the infaunal community.

In addition to preventing accumulation of toxic chemicals up the food chain, ecosystem "health" implies that a stable habitat and food supply must be maintained for the higher trophic levels. Regional ecological effects can be postulated as follows:

- Declines in ophiuroids and crustaceans may adversely affect selective-feeders (particularly juveniles) and other predators, whereas overall enrichment may enhance opportunistic predators (such as English sole).
- Regional enrichment of biota such as shrimp and ophiuroids may balance or exceed adverse effects (and may help offset impoverishment at OE2 and sometimes OE1).
- Bioturbation in the MI and LI zones is likely reduced due to a decline or elimination of larger fauna such as echinoderms, but may be partially offset by an increase in near-surface, smaller opportunistic bioturbators such as small polychaetes. Related changes to "cleansing" and burial rates of contaminants are not clear, based on the current monitoring program.
- Potential for bio-accumulation or magnification of toxic contaminants up the food chain needs to be addressed in a more region-wide context
- Regional recruitment potential and biodiversity are likely unaffected due to the well-flushed, open location and extensive larval distribution.

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In conclusion, the spatial scale and extent of organic enrichment effects from the Iona outfall are unlikely to have adverse effects on higher trophic levels.

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